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Combined temporal and spectral measurement of infrared supercontinuum performed by up-conversion in a non-linear crystal

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Abstract: Up-converting infrared supercontinuum allows a direct measurement of its temporal and spectral properties. The resulting spectrogram reveals that higher order spatial modes play an important role in supercontinuum generation in step index fibres.

I. INTRODUCTION

During the last decades supercontinuum (SC) generation has been investigated extensively, both theoretically and experimentally[1]. The bright light source is applied in numerous areas ranging from optical combs[2] to microscopy[3]. Recently SC was pushed into the infrared region, by applying non-silica fibres based on materials such as ZBLAN or Chalcogenide[4]. These fibres are often step index fibres. Higher order modes (HOMs) are therefore accessible below some cut-off wavelength. The influence of HOMs on SC generation is a challenging problem and is therefore often neglected when modelling SC (Ref. 5). Here we present how up-conversion of supercontinuum can be used as a tool for investigating the effect of HOMs in the SC generation process. Furthermore the measured spectrogram reveals the dispersion properties of the lowest order modes.

The experimental setup is seen in Figure 1. A 1 kHz, 100 fs laser system combined with an OPA is used to pump 30 cm of ZBLAN step index fibre with a core diameter of 10 µm and a numerical aperture of NA = 0.2. The OPA has a tunable wavelength range from 1200 nm to 2600 nm. The resulting SC is focused with a parabolic mirror in a non-linear crystal. Overlapping the SC with the residual 800 nm beam from the laser source and choosing the correct phase matching angle of the crystal the two beams are sum frequency mixed. This up-converted signal is measured with a Si-diode in combination with a box-car integrator. Changing the path length of the 800 nm beam determines the temporal axis and the phase matching angle of the crystal determines the spectral axis. In this way a spectrogram of the SC is made.

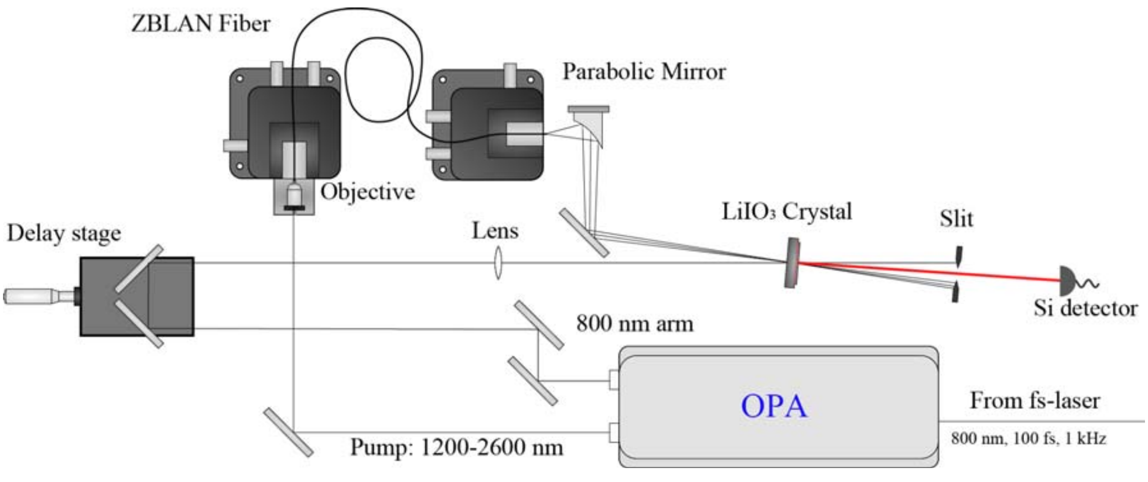

Fig. 1. A step index ZBLAN fibre is pumped by an OPA and the resulting output is sum-frequency mixed with 800 nm in a non-linear crystal.

II. RESULTS

Figure 2 shows the measured spectrogram where the ZBLAN fibre is pumped at 1800 nm with a pulse peak power of 300 kW. The fibre has a zero dispersion wavelength around 1650 nm, meaning that the fibre is pumped in the anomalous dispersion regime and the SC generation is governed by soliton related dynamics. The figure shows that the SC spans the region from 900 nm to 3000 nm. A number of echoes are seen at the pump wavelength. These correspond to free induction decay induced by the fs-pump as is propagates in the ambient air before it is launched into the fibre. If the pump is moved to 2200 nm where the absorption is lower the echoes disappear.

Theoretical dispersion profiles of the three lowest modes are also plotted in the figure. These are calculated by propagating white light along the fibre with respect to the group velocity of the modes. It is seen that there is a good agreement between the measured data and the theoretical calculated modes. An interesting feature of the spectrogram is that the LP21 mode is exited even though it has cut-off below the pump wavelength. This light cannot come from the pump, but must have been coupled to the LP21 mode during the SC generation process. The light in the LP11 mode could be pump light, but if the pump power is lowered, light is only seen in the fundamental LP01 mode, indicating that the LP11 mode likewise is excited by the SC process. Pumping the fibre above the cut-off wavelength of the LP11 mode (not shown) a coupling to both the LP11 and LP21 is still seen. Together these observations underline that there must be a mechanism that couples light from the fundamental mode into the HOMs. So far our results indicate that Raman scattering in the first mm is responsible for the exiting of HOMs. In order to show how the specific coupling mechanism a simulation including HOMs in SC generation is preferred. Including HOMs in SC calculations will thus give another degree of freedom for tailoring SC.

The good resemblance between the measured mode dispersion profiles and the calculated also mean that this method can be used to determine dispersion profiles of the lowest modes. Up-converting SC furthermore has the benefit that Si-based technology can be used to measure the light. As Si-diodes are much faster and less expensive compared to mid-infrared technology, this can prove to be a method for doing fast measurements in the IR region.

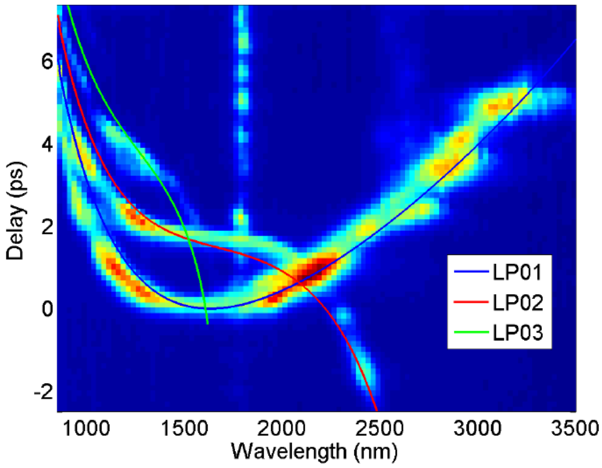

Fig. 2. Spectrogram of supercontinuum generated in ZBLAN fibre. Pump at 1800 nm.

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